Growing microalgae for CO_2 sequestration, wastewater remediation, fuel and other valuable products

Brian Kirke
Sustainable Energy Centre
University of SA

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Summary. Aquatic microalgae can use sunlight, nutrients in wastewater and CO_2 and waste heat from power station flue gas to produce biomass rapidly and efficiently. This biomass can be used to produce transport fuels, plastics, fertilizers and feed for livestock and aquaculture. Thus algae offer the possibility of addressing 3 major problems at once:

1. CO_2 emissions
2. Nutrient pollution of waterways
3. Depletion of fossil fuels.

The potential benefits are enormous, and research into algae production using wastewater and power station emissions should be given a high priority.

Economics: single versus multi-purpose operations. Studies to date (see for example Pedroni et al, 2006, Benemann, 2003) indicate that

(i) Multi-purpose operations at suitable sites offer much better prospects of economic viability than single-purpose cultivation of algae for fuel production, which is unlikely to be economically competitive with fossil fuels at present prices.

(ii) The most economical way to grow algae is in shallow, unlined, mixed open raceway ponds, using municipal or agricultural wastewater to supply both water and nutrients, and where practicable, power station flue gas as a source of carbon.

(iii) Economic viability will depend on climate and availability of land close to wastewater treatment plants and power stations.

Adelaide's competitive advantage. Most of Adelaide's wastewater, about 120 ML/day, is treated at Bolivar, which is only about 7 km across Barker Inlet from 4 power stations (Torrens Island, Pelican Point, Quarantine and Osborne), with a combined capacity of about 2000 MW. Although these run on natural gas and so produce only about half as much CO_2 per MWh as coal fired power stations (about 400 kg/MWh compared to 800 for black coal and 1000 for brown coal), they still produce a lot of CO_2. There is flat, undeveloped land both at Bolivar and on Torrens Island. Adelaide has a mild, sunny climate suitable for algaculture most of the year. Bolivar and Torrens Island would be ideal sites for pond trials.

Sequestration of power station CO_2 emissions. Unlike other plants, aquatic microalgae can directly absorb over 90% of the CO_2 in flue gas (Sheehan, 1998:12, 243). Where land is available, ponds could be located close to existing power stations and flue gas could be piped directly to ponds, thus avoiding both the cost of bottled CO_2 to stimulate algal growth and the financial and energy costs of geosequestration of power station emissions, in which the CO_2 (typically up to 13% of flue gas according to Sheehan, 1998:4) must be separated from the other gases, then compressed, then piped usually hundreds of km to suitable geological formations. Some waste heat from the power station could also be utilized in winter.

Wastewater treatment. Algae are currently used for secondary treatment of wastewater (BOD reduction) in unmixed wastewater treatment lagoons and in tertiary treatment (nutrient removal). By mixing the water, the process can be accelerated, thus reducing the land area required. Mixed raceway ponds are an alternative to activated sludge processes, offering both lower energy consumption and a valuable product.

Biomass fuels. Under favourable conditions some algae strains have produced over 50 gm of dry biomass per sq m per day, which translates to 182 tonnes/Ha per year. According to Sheehan, 1998:39, one chlorella strain achieved 55.5 g dry weight/m^2/d. Chlorella is a fast growing species of green algae which grows naturally in SA. Realistically 100 T/Ha/year of dry matter might be achieved, many times more than can be achieved using any other life form used for biomass energy production, such as forests, sugar cane, canola or oil palms.

Botrycoccus braunii, a slow growing species, can contain over 50% of oil, mostly in the form of hydrocarbons. Genetically engineered strains may be made to grow faster. One naturally occurring chlorella strain in the SE of the USA produced 28.6-32.4% lipids (Sheehan, 1998:41), from which biodiesel can easily be produced. From these figures it can be expected that, with some further selective breeding, some 30 kL of biodiesel could be produced per Ha of pond per year, with a current retail value of about $40,000. Benemann (2003:26) estimated the capital cost of raceway mixed ponds, assuming flat land and clay soils, at USD $60,000 per Ha, about AUD 80,000.

In addition to liquid fuel production, much of the non-oil part of the algal biomass can be digested anaerobically to produce biogas, which can be used in stationary power generation.

Nitrogen fertilizer, stock and aquaculture feed. Various possibilities exist for the residue of biomass which can not be converted to fuel.

Plastics. Benemann (2003:20) mentions the possibility of producing bioplastics as a large volume co-product.

Worldwide R&D. Several companies are developing techniques to use algae for fuel production and/or CO_2 capture, most in the US, for example Green Fuel Technologies, GreenShift and Solazyme. Websites are given below. A New Zealand company, Aquaflow Bionomic Corporation, claims to have achieved the world's first commercial production of bio-diesel from "wild" algae outside the laboratory.

Australian work in this field. There are several initiatives:

1. SARDI (the SA R&D Institute) has just started a 3 year, $1m project in collaboration with ARF (Aust Renewable Fuels) with an emphasis on photobioreactor work to identify suitable algae to grow in saline water, such as in the Riverland salt interception area.
2. ARF is an Australian company currently developing two biodiesel plants, one in Adelaide and another in Picton, Western Australia.
3. New York based company Vision Energy plans to use cooking oil to produce biodiesel in Victor Smorgon’s facility at Laverton, WA.
4. Victor Smorgon have also signed a licensing agreement with Greenfuel Technologies Corporation of Cambridge, Massachusetts, to develop photobioreactor technology to capture CO_2 emissions.
5. SQC is supporting laboratory studies at Flinders University on botrycoccus brownii.

6. According to http://thefraserdomain.typepad.com/energy/2006/06/petrsun_enters_.html, PetroSun Drilling Inc. (PSUD.PK), has a subsidiary, Algae BioFuels Inc., which will be engaged in R&D into algae cultivation as an energy source in the production of biodiesel in Arizona and Australia.
7. Natural Fuel Australia Ltd ("NFAL"), 50% owned by Babcock & Brown Environmental Infrastructure Ltd., are constructing a biodiesel production facility in Darwin.
8. Lurgi Pacific is currently constructing a biofuel plant at Henderson, Western Australia.
9. There may be other private ventures which would understandably be keeping a low profile so nobody steals their IP.

ISST-SA Water Research Proposal.
The following is an engineering perspective, given my own background and the facts that (i) considerable work has been done and is being done by biologists, and (ii) both engineering and microbiological work is needed.

1. **Contact the International Network on biofixation of CO_2** and seek feedback on the following proposals.

2. **Ponds.** Identify a suitable site and construct several small, scaleable open raceway ponds with paddle wheel mixer/circulators. The emphasis in most current R&D is on bioreactors, which are useful for producing innoculant for large ponds but are unlikely to be economic for mass culture. According to Pedroni et al (2006:5), a project in Italy on microalgae biofixation of CO_2 compared the productivities of algal cultures in open ponds and closed bioreactors and found them to be almost identical. Given that the capital cost of bioreactors is about 10 times higher than that of open ponds (Pedroni et al, 2006:6), and that capital cost is likely to be the main factor limiting this technology, it would seem to make sense to do some work on open pond cultures to try to demonstrate high productivities in local species under local conditions, and to develop low cost techniques for harvesting and dewatering which could be scaled up for large scale production.

3. **Fill ponds with nutrient-rich wastewater**, probably after primary treatment to remove solids but before secondary treatment so BOD is still high. Ponds would ideally be located either at Bolivar, near the source of nutrient-rich water, or adjacent to a power station where CO_2 can be easily piped to the ponds. Choice of site may depend on availability of land and the relative costs of transporting CO_2 to Bolivar, or wastewater to a power station.

4. **Identify a source of CO_2.** Ideally a pipeline would be constructed from one of the 4 nearby power stations. Of these,
    - **(i)** Torrens Island (1280 MW) is owned and operated by Truenergy, a Victorian company 100% owned by CLP Hong Kong, and there doesn't appear to be much local environmental focus, but we could approach them.
    - **(ii)** Pelican Point (320 MW), owner International Power, who also own Hazelwood, a dirty Latrobe Valley power station.
    - **(iii)** Quarantine (95 MW), opened in 2002, 100% owned, operated and maintained by Origin Energy, who claim "a strong corporate commitment to this State, as we trace our beginnings back to 1864 through the South Australian Gas Company." Contact Andrew Stock, Executive General Manager Generation, Phone (08) 8217 5718,

Mobile 0417 867 470, or Yvette Reade, Manager Public Relations, Phone (08) 8217 5376, Mobile 0419 043 042)

(iv) Osborne (180 MW): "Australia's Largest Gas Fuelled Co-Generation Power Plant. An Origin Energy – ATCO Power joint venture facility."

Of these, Quarantine is the closest to Bolivar, and Origin Energy are likely to be more favourably disposed than the other owners to such a project.

5. **See what species naturally populate the ponds.** Benemann's preferred option is "to isolate competitive strains in scaled down mass culture ponds and then study physiological manipulations and genetic improvements that would increase the productivity and harvestability of such strains, while maintaining their competitiveness in the open pond culture environment" (Benemann, 2003:23). He goes on to say "each process, application, even site will require its own suite of algal strains…. R&D and even pilot-scale testing of the proposed wastewater treatment processes can be initiated without specific algal strains in hand. Promising algal strains would be isolated from species invading and dominating such ponds."

6. **Collaborate with SARDI's Biofuels Project:** Dr Kevin Williams, Principal Scientist – Biofuels, and Dr Sasi Nayar, Senior Research Officer, Algae Biofuels project. Dr Nayar heads the project to identify suitable algal strains.

7. **Investigate harvesting techniques.** This part of the work might be undertaken by AMRDC, the Agricultural Machinery R&D Centre at UniSA. According to Benemann (2003:25), "Reliable, low cost harvesting has been the *single most limiting factor* in expanding microalgae applications in wastewater treatment and is an R&D priority." Pedroni et al (2006) state: "harvesting still requires considerable more R&D, and it must be developed for specific algal strains, as no technique is universally applicable." Thus work will be needed to identify the most cost-effective harvesting techniques for the algal strains selected for mass culture. These may include bioflocculation and/or microfiltration.

8. **Investigate techniques for separating lipids from biomass.** These may include such things as (i) ultrasound to rupture cell walls and release lipids, (ii) use of solvents to dissolve oils and separate them from carbohydrate and cellulose. If only biogas/methane is to be produced from the residue after oils have been extracted, dewatering may not be necessary.

Possible supporters of this proposal

1. **SA Water**. Should be interested in stripping nutrients from wastewater, if not at Bolivar, at other smaller WWTPs. They should also be interested in creating value out of wastewater. They are involved in a CRC bid with UniSA and SARDI Integrated Resource Systems to produce useful products from wastewater. This proposal should be right in line with that aim.
2. **United Water**. As for SA Water.
3. **UniSA Water Research Centre.** As for SA Water.
4. **SARDI.** 2 branches, (i) biofuels (Dr Williams and Dr Nayar) and (ii) Martin Kumar, Integrated Resource Systems (not connected to the biofuels group): agricultural waste stream remediation, based at Roseworthy and West Beach.
5. **Origin Energy.** It would be good publicity to be seen to be supporting biosequestration of CO_2, and the prospect of carbon credits if successful may also be attractive.
6. **Local biodiesel manufacturers and retailers ARF, SAFF and any other players manufacturing biodiesel** should be interested in expanded sources of feedstock.

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